PB-237 732-T

THE EFFECT OF DUST AND SOOT ON THE GROWTH OF SPRUCE TREES

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1960

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U. S. DEPARTMENT OF COMMERCE

PB 237 732-T

331063

APTIC 49914 EPA-TR 84-73

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[Die Wirkung von Staub und Russ auf den Zuwachs der Fichte]

Der Forst- und Holzwirt, Vol. 15, No. 13, pp. 245-248, 1960.

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Springfield VA 22151

Translated for APTIC by
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THE EFFECT OF DUST AND SOOT ON THE GROWTH OF SPRUCE TREES*

I. Introduction and Formulation of the Question

The fact is uncontested today that certain gases, such as sulfurous acid, hydrogen chloride, hydrogen fluoride, and others, as pollutant components of the air, produce severe damage to forest trees and cultivated plants. What is contested and is not uniformly agreed upon, on the other hand, is the question whether solid pollutants in the air, primarily dust pollutants, are injurious to plant growth.

Some authors affirm that dust-like components from waste gases do cause damage to plant growth; many others deny this influence. The opinion predominates that dust and soot play a much more negligible role as plant-growth inhibitors than do gaseous air pollutants.

Berge conducted open-air vegetation experiments for several years in which winter wheat, winter rye, and winter rape were dusted daily per square meter with various types of dust (cement-oven dust, lime dust, bituminous and brown-coal dust, iron dust) and found in comparison with untreated plants, negligible yield losses (up to -7%) in straw and kernels, only in individual cases, contrasting in numerous cases with yield gains up to 16%.

On the other hand, losses in quantity and quality, especially as far as vegetable and fruit growing is concerned, have been described as a result of severe exposure to dust. Fortmann, for example, was unable to raise either marketable head lettuce or cyclamen plants in under-glass

cultivations exposed to 2.1 g/m^2 flue dust sedimentation. On a three-year average the dust covering on the protective glass surfaces of the cultivation boxes caused yield losses in head lettuce from 18 to 79%, depending on the thickness of the covering. These yield losses are explained as resulting from the withdrawal of sunlight and consequently a reduction in assimilation capacity. Balks, too, considers a reduction in assimilation through the limitation of light as a result of a more or less thick layer of dust possible.

Czaja conducted a critical study on the available literature dealing with the question on "the effect of cement dust on plants," which is not very extensive and based on very few original papers, and came to the conclusion on the basis of his own preliminary investigations on many deciduous plants in the vicinity of cement works that care must be taken in asserting that cement dust does not influence plants. "This assertion is not supported by any evidence. The examination of plants covered with cement dust yields evidence to the contrary. Seen from the point of view of plant physiology, this is quite understandable." Czaja demonstrated various kinds of damage to plants in his investigations on the effect of cement dust:

1. Visible damage: discoloration of the leaves, dead branches and twig tips;

2. invisible damage: deformed, yellowed, caked chloroplasts (microscopic determinations);

3. disruptions in growth mechanisms: small leaf size on side facing the source of the dust;

4. physiological disruptions: starch blockage in leaves and bark.

In going over the pertinent literature available to me, I get the impression that effects of dust-like air pollutants on plant growth generally are regarded as negligible and of no great importance in comparison with gaseous pollutants. That is the impression, for example, in the comprehensive presentation of the Association of Large Boiler Owners "Air pollution caused by Fumes from Steam Boilers," ["Luftverunreinigung durch Rauchgase aus Dampfkesselanlagen"] Chapter IV; that a physico-mechanical influence of plant growth through dust is implausible from the start because otherwise, as Heselhoff also suggests, dust-like substances, which are scattered by the wind, on fields along the highways for example, would have to inhibit plant growth everywhere. It says literally in this connection: "It can, therefore, be assumed that no disadvantage to plant growth occurs as far as materials insoluble in water are concerned." At another point in the same paper it says: "Today no deleterious effects on plants are generally ascribed to soot. Only soluble extracts from brown-coal and bituminous-coal soot (sulfuric acid, sulfate, tar components, etc.) can be considered to have some disadvantageous effects."

This author does not know of any detailed experiments on the effect of dust and soot on forest trees. Since on the one hand professional literature stresses for the most part the harmlessness of solid air pollutants, yet on the other hand many an observation seems to suggest the possibility of their being harmful (for example, shorter shoots and needles on spruce trees continuously exposed to heavy dust), it appeared purposeful to settle the question experimentally.

Therefore, the question for our first experiment was: can a very heavy and sustained exposure to dust and soot impair the growth capacity of spruce trees? To answer this question the following experiment was conducted in 1956 and 1957 and in the spring of 1958.

II. Conduct of the Experiment

For this experiment 40 three-year-old spruce grafts from one clone, as far as possible of the same size and all equally developed, were selected in the Grafrath Experimental Gardens at the beginning of March 1956. The sprigs for the grafts used in this experiment all came from the same mother tree, so that the young plants included in the experiment all had the same heredity. Therefore, right from the start individual differences in regard to susceptibility and sensitivity to dust and soot were eliminated. For that reason we were able to limit ourselves in the course of the experiment to a smaller number of plants. The grafts were set in large, perforated flower pots, the dimensions of which were chosen so that the grafts were able to grow satisfactorily up to the end of the experiment, that is, until they reached five years of age.

We used the following types of dust:

1. lime-rich road dust from a secondary road in Wildenroth near Grafrath in the Upper Bavarian moraine region,

2. calcium carbonate in the state used as manuring lime,

3. soot from the chimney of the Experimental Gardens' service building, half the furnaces of which were fired with wood and

half with bituminous coal.

After the three-year-old spruce grafts had been plotted in the beginning of March 1965 and were well rooted after several weeks, they were covered with dust for the first time toward the end of April before the sprouts appeared. Each plant of a group received a uniform quantity of dust by means of a simple blower:

Group I:

pots no. 1 through 10 received no dust (untreated control plants),

Group II:

pots no. 11 through 20, each plant received 25 g of road dust,

Group III:

pots no. 21 through 30, each plant received 15 g of calcium carbonate,

Group IV:

pots no. 31 through 40, each plant received 10 g of soot.

At the beginning of May the spruces developed their new shoots and needles, which were not exposed to the dust particles until they were fully developed. At the end of May, following full formation of the shoots and needles, the plants were dusted for a second time, each plant with the same amount as the first time; only this time the dust and soot were distributed primarily on the newly formed needles.

The plants subsequently were bedded down in a glass-covered cold-bed box in the ground. The glass was placed at an appropriate height for the sun's rays and daytime heat so that too much heat was avoided. Thus, the plants received during the entire 1956 growing season no rain at all, with

the result that the applied dust could not be washed off. The amounts of water necessary for each pot were measured and, if needed, supplied to the earth by means of a watering can so that no water spray would come in contact with the needles. After the close of the 1956 growing season toward the end of September, the glass covering was removed; the plants were still in their cold-bed boxes with the individual pots set into the ground but were exposed to weather and climate during the winter of 1956/1957, the entire 1957 growing season, and the following winter of 1957/1958.

The experiment was terminated in the spring of 1958 with the measuring of the height increment of each plant. Next, the above-ground parts of each plant were analyzed in such a manner that the shoots and needles formed in 1957 and 1956 growing periods and in previous years could be weighed separately in both the fresh and air-dried state.

The experiment was looked after in exemplary fashion in the Experimental Garden by master gardeners Kraft and Menzinger. The latter also carried out the final measuring and weighing operations. Their participation is here gratefully acknowledged.

III. Experiment Results

The results of the final measurements and weighings are summarized in the survey table. The last four columns in this table (2 through 5) contain on each line the average values of 8 similarly treated plants within a group, and the pertinent mean error for control plants and for those treated with road dust, lime, or soot. Only 8 of these 10 plants in each group were included to the Forestry and Botany Institute for

metabolism analysis (measurement of the assimilation, respiration and transpiration). In view of the uniformity in heredity of the plants, the 8 plants in each group sufficed, as the very low error deviations indicate.

The fact that spruce plants used in the experiment and collected into four groups at the outset of the experiment were well suited for comparative purposes is shown by the values of lines 1, 2, 3, and 6 of the survey table, and, in particular, the comparison of the values for untreated plants, on the one hand (column 2), and those for plants that had been treated with road dust and lime (columns 3 and 4) on the other. The fresh weight of all the shoots without needles (column 2) formed in 1956 as well as the uniform data of the needles by themselves (column 3) coincide well for treated and untreated plants. Although needles from 1956 had been treated with dust for the entire growing season, their weight was approximately the same as that of the control (untreated) plants. The needle mass was determined by the buds already formed the previous year prior to the exposure to dust. Likewise, the comparison of the air-dry weight of all needles developed before 1956 (line 6) is adequate proof for the average comparability of the assimilation organs of the plants from the three groups.

That the group of plants subjected to soot cannot be included in this comparison and that they show lower values (column 5) throughout as far as weight data for the needles are concerned is due to the fact that all plants exposed to soot had lost part of their needles from the 1956 and 1955 growth, and all the needles from earlier growth from

SURVEY TABLE

Measuring and Weighing Results of the Experiment with Young Spruces Treated with Dust and Soot

Column / line	WEIGHING AND MEASURING DETERMINATIONS	Untreated control plants	Plants treated with		
			Road dust	Lime	Soot
	1	2	3	4	5
	Average values for:				
1	fresh weight of all shoots with needles formed in 1956 in g	35.0 ± 1.1	36.2 ± 0.9	34.8 ± 0.9	28.9 ± 0.9
2	air-dry weight of all shoots without needles formed in 1956 in g	6.0 ± 0.5	5.9 ± 0.5	5.8 ± 0.4	5.8 ± 0.3
3	air-dry weight of all needles formed in 1956 in g	11.2 ± 0.8	12.2 ± 0.6	12.3 ± 0.8	10.6 ± 0.7
4	fresh weight of all shoots with needles formed before 1956 in g	49.4 ± 2.0	46.3 ± 1.4	46.9 ± 1.4	27.5 ± 1.2
5	air-dry weight of all shoots (above-ground wood mass) without needles formed before 1956 in g	16.5 ± 1.2	17.5 ± 1.1	18.1 ± 0.5	14.1 ± 1.2
6	air-dry weight of all needles formed before 1956 in g	7.0 ± 0.7	6.9 ± 0.5	7.5 ± 0.7	2.6 ± 0.4
7	root weight fresh in g	38.1 ± 1.2	34.6 ± 1.4	28.8 ± 0.7	19.9 ± 1.8
8	root weight, air-dried, in g	21.2 ± 0.8	19.8 ± 0.9	16.9 ± 1.0	13.5 ± 1.2
9	growth increment 1957 in cm	10.9 ± 0.6	5.6 ± 0.7	6.5 ± 0.7	1.9 ± 0.4
10	fresh weight of all shoots with needles formed in 1957 in g	33.1 ± 0.6	23.8 ± 0.7	17.8 ± 1.6	10.6 ± 1.2
11	air-dry weight of all shoots without needles formed in 1957 in g	5.9 ± 0.3	4.4 ± 0.2	3.9 ± 0.4	2.4 ± 0.2
12	air-dry weight of all needles formed in 1957 in g	9.8 ± 0.7	6.8 ± 0.5	4.5 ± 0.4	3.1 ± 0.4

corrosion stemming from the effect of the soot.

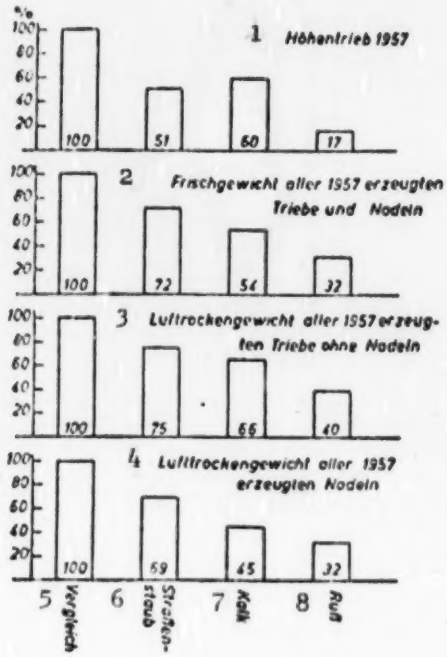

Figure 1. Percentage comparison of growth performance of above-ground plant parts grown in 1957 from five-year-old spruce clones (including untreated spruce and those treated with road dust, lime and soot) in the year following their exposure to dust (performance of the untreated control plants = 100).

1 - growth increment 1957; 2 - fresh weight of all shoots and needles produced in 1957; 3 - air-dry weight of all shoots without needles produced in 1957; 4 - air-dry weight of all needles produced in 1957; 5 - control plants; 6 - road dust; 7 - lime; 8 - soot.

The fresh weight of all shoots formed before 1956 with needles (line 4) and the air-dry weight of all shoots without needles (line 5) formed before 1956, also point in the same direction toward good comparability in the initial state.

The effect of the dust and soot layer on the assimilation organs during the entire 1956 growing season on the growth of the above-ground parts in the following year are shown by values 9 through 12 of the survey table. The data shown on lines 7 and 8 reflect the growth of the roots.

While the survey table contains absolute values, the productivity in percent for untreated and treated groups of plants are illustrated in Figures 1 and 2, where productivity of the untreated plant group was taken as 100.

The 1957 growth increment declined in the case of plants treated with road dust and lime to about one half that of the control plants, in the case of plants treated with soot to about one-sixth.

The weight results are just as unequivocal as the measurement results of the annual growth increment. In the fresh weight of all shoots with needles produced in 1957, in the air-dry weight of all shoots without needles produced in 1957 and likewise in the air-dry weight of all needles by themselves formed in 1957, the plants treated with road dust performed about 3/4 as well as the control plants, those treated with lime dust about one half as well, and those with soot about one third as well.

In doing this, we attach no special significance to absolute numerical values. The experiment did, however, show unequivocally that a dense covering of the assimilating needles with dust or soot during an entire growing season can reduce the ensuing year's growth considerably.

The resultant slighter assimilation performance also critically affects the growth of the roots (lines 7 and 8 of the survey table and Figure 2).

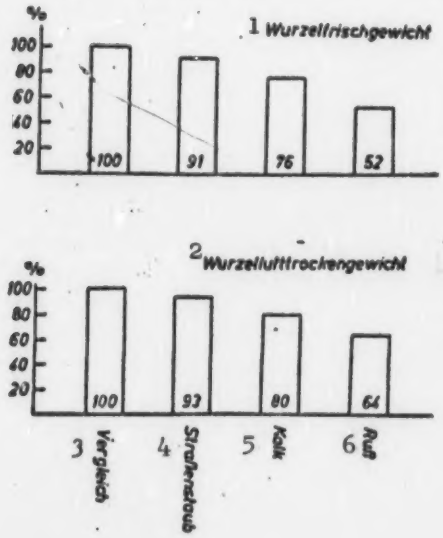

Figure 2. Percentage comparison of growth performance of fresh and dry root weight among five-year-old spruce clones (including untreated spruce and those treated with road dust, lime, and soot) in the year following their exposure to dust (performance of the untreated control plants = 100).

1 - fresh weight of the roots; 2 - air-dry weight of the roots; 3 - control plants; 4 - road dust; 5 - lime; 6 - soot.

IV. Discussion

One objection can be raised to the experiment described here: the experimental plants were not exposed to dust under natural conditions but rather to exposure under glass so that the dust layer could not be washed away by rain. Instead of "natural" open-air conditions, perhaps it would be better to say "conditions approaching reality"; for with the exception of soil erosion, no exposure to dust is "natural," but

always caused by technological or other acts of man. Reproach on the basis of unreality loses much of its validity inasmuch as it was not the goal of this experiment to examine processes as similar as possible to actual phenomena, but primarily to settle the question as to whether growth performance can be impaired through severe and persistent exposure of the needles to dust and soot.

That our method of applying dust was not at all so far removed from reality can be illustrated by the following data. Each plant in Group II received 2 x 25 g of road dust, in Group III 2 x 15 g of calcium carbonate, and in Group IV 2 x 10 g of soot. Since the 10 plants in their pots embedded in the ground occupied an area of about one square meter, this method of dust application corresponds approximately to a total amount of 500 g per square meter for Group II, 300 g from Group III and 200 g for Group IV. In industrial areas as measurement data frequently show, 2 to 3 g of dust daily settles on the ground, up to 6 g in extreme cases in the Ruhr Area, and up to 15 g of dust in brown-coal areas. With such extreme sedimentation, equally large quantities would settle on the surface in 13 to 20 days in industrial areas as we applied in our two doses at an interval of several weeks. Moreover, if we assume that following such a dense dust sedimentation it does not rain for 4 to 6 weeks, then the differences between our experiment, which was intentionally designed as an extreme case, and the realistic conditions of nature are no longer so great.

We endeavored to arrange a second and consecutive experiment over a longer period of time, after the first experiment with its extremely

high quantities of dust yielded such an unequivocal result, one that would more closely resemble natural conditions. Eight times 12 well-developed, 4 year-old, spruces were planted on a 1 m^2 plot. While half of the experimental fields, that is, 4 x 12 spruces, were to remain untreated as control plants, the remaining of 4 x 12 spruces arranged in checkerboard fashion were to be treated with 15 g/1 m^2 of dust at the start of each week.

The experiment was again being conducted with various kinds of dust and was to be continued over several years. The plants will be weighed and dissected only after 3, or perhaps 5 years, while growth increment and possibly starch growth will be checked annually at the end of each growing season.

Our first experiment affirms nothing specific about the reasons that caused the growth decline following heavy and persistent exposure to dust effects. According to Fortmann's experiments we could scarcely go wrong, however, in primarily holding the withdrawal of light as a result of the thick dust layer and the consequent limitation of assimilation responsible for decreased growth. It can be safely assumed that in exposure to soot not only the mechanical and physical retardation stemming from the withholding of light, but also acute corrosion were involved which is shown by the complete loss of all needles that had been formed earlier.

Let us briefly mention that dust does not equal dust, but that the effect can be quite different according to its physical quality (grain size) and its chemical composition. It is just as true that dust

particles cannot only impair, but also promote, under certain circumstances, plant growth. Thus, improved growth is possible primarily through fertilizing and soil enrichment, as well as through creating a more favorable pH value. Moreover, a dust layer on leaves can serve as a sort of protection against evaporation and transpiration and in dry seasons enhance the function of the cuticula of the epidermic cells.

The relationships are thus quite complex and involved. In forest management, it is in the final analysis important to know whether heavy exposure to certain types of dust is beneficial or harmful to plant growth.

In answering this question perhaps the experiment illustrated here has made its small contribution. The conduct of new and more comprehensive experiments should serve the same purpose.

V. Summary of the Results

1. The effect of very thorough and persistent exposure to road dust, calcium carbonate and soot on plant growth, was investigated in an experiment with 40 spruces of common heredity that were three years old at the start of the experiment and five years old at its conclusion. The plants were exposed for the entire 1956 growing season to the effect of a heavy coating of dust. In the following year, the growth performance and the production of shoots and needle mass in plants treated with dust were substantially below the untreated control plants. The root mass produced was also smaller in the treated plants than in those untreated.

2. The considerable growth retardation after a heavy layering of dust lasting one growing season is primarily explained by the withdrawal of light and the resultant reduction in assimilation performance. In exposure to soot, however, the corrosive effect of the chemicals contained in the soot increased the extent of the damage to the plants.

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